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Low-Cost Tubular Antenna Deployer for WISP-2

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Abstract

A new tubular boom deployment mechanism has been designed, built, and flown as part of the second Waves In Space Program (WISP-2) through Cornell University. For this program, two booms were needed to form a dipole antenna but existing units were found to be too complicated and costly. A low-cost alternative was developed which combined flight-proven tubular boom technology with a new support and deployment mechanism. The simplicity of this new design was a major factor in providing a highly reliable and cost-effective system.

Mission Description

The WISP-2 experiment was launched from Wallops Island, VA on July 22, 1993 onboard a Black Brant X rocket. The 750-second experiment reached an altitude of 500 km and covered a distance of 500 km before burning up on its return to the atmosphere. Shortly before the apogee of the flight, the payload separated into two units to form a transmitter and a receiver. Onboard the transmitter unit, the two tubular booms deployed out of opposite sides of the spinning spacecraft to form a 40-meter dipole antenna. The three main instruments onboard measured electrical, magnetic, and particle properties. Data from these instruments verified that the booms deployed successfully.

Description

The new boom deployment mechanism, shown in Figure 1, was designed to contain and support the stowed antenna during launch and then enable the antenna to deploy on command. The mechanism consisted of three main components: the base, the tubular boom antenna, and the stowage spool. Deployment in space was initiated by actuating a pin-puller. The first part of deployment was controlled by the geared kick-off feature as shown in Figure 2. The boom continued to self deploy and once it was fully extended, the spool simply flew off the end. Because this was a non-orbital flight, restrictions on generating space debris did not apply.

Each assembly measured 10 by 13 cm on the base by 13 cm tall. The mass of the mechanism (excluding the tubular boom) was 0.86 Kg. The 20-meter-long tubular boom was 0.45 Kg and the Kapton insulation was 0.05 Kg for a total system mass of only 1.36 Kg. Four clearance holes were provided to mount the unit to the spacecraft.

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The Base

The main part of the base structure was made by bolting two rectangular side plates onto a square base plate to form a simple "U" section. The sides and base were made out of 12.7 mm (0.5 inch) stock Delrin plate which had several advantages. This material was readily available, easy to machine, inexpensive to purchase, and provided good electrical insulation.

The relatively thick section of material allowed the use of oversized screws which could be threaded directly into the plastic plates without the need for threaded inserts. Typically, 10 to 15 threads were engaged which provided a good margin over the required strength. A thread locking compound was used to hold the screws in place. Slots were machined into the side plates which supported the stowed spool during launch and guided the spool out of the mechanism during the first part of deployment. Contained within the thick side plates were two spring-loaded plungers which provided an initial push on the spool away from the base.

The geared kick-off feature also held the stowed boom in place during launch. A short section of gear rack was mounted to each side plate. A rocker plate, with two single toothed sections of rack attached, was sandwiched between the two side plates. The spool was captured in the base by the rack on one side of each spool gear and the single gear tooth on the other. The rocker plate was held in place by a small pyrotechnic pin-puller.

A flanged aluminum post was attached to the base plate. The root of the boom was attached to and supported by the post. Electrical attachment to the boom was provided by a single tapped hole in the flange.

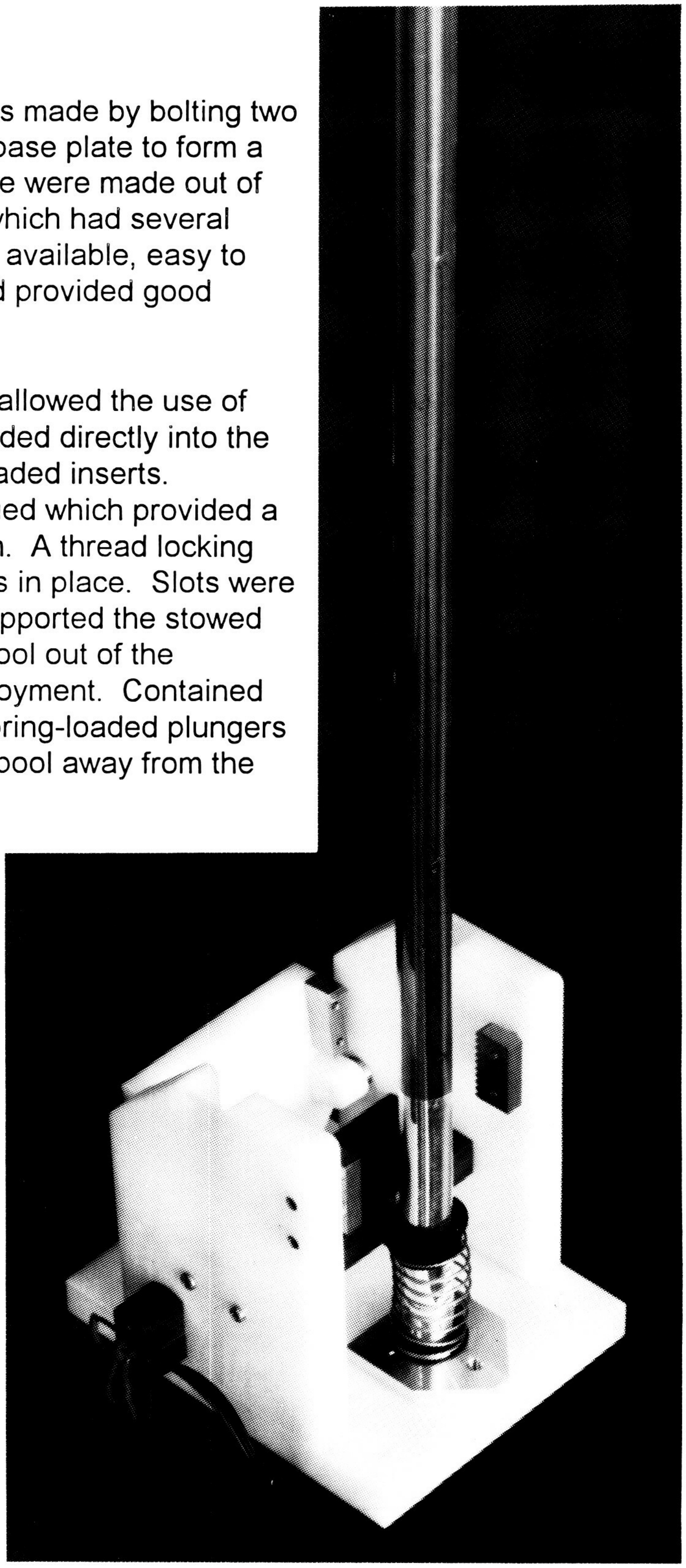

Figure 1. Mechanism With Boom Deployed

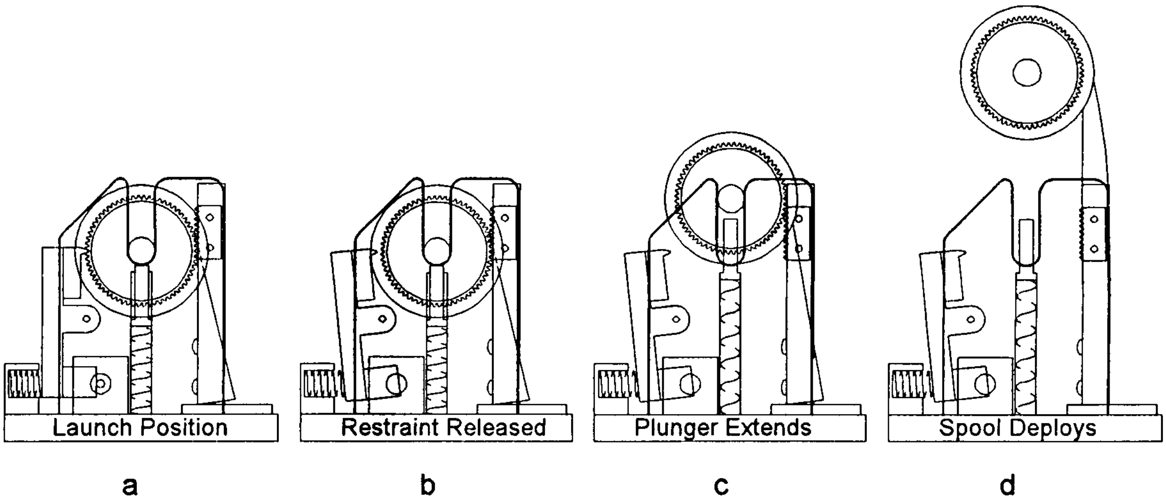

Figure 2. Initial Deployment Sequence

a. In the launch position, the stowed boom on the spool was captured by the geared kick-off feature.

b. Once in space, a pyrotechnically actuated pin-puller released the launch restraint mechanism which allowed the spool to unwind and deploy the boom.

c. Two spring-loaded plungers provided the initial force to push the spool away from the base. The rack and gear forced the spool to rotate as it moved up the guide slots.

d. The guide slots directed the deploying spool away from the base. The initial deployment sequence took less than 1 second. The time to deploy the entire 20-meter boom was less than 10 seconds.

Tubular Boom

The antenna element for this program was specified to be a self-deploying tubular boom, 14 mm diameter by 20 meter long, made of silver-plated, beryllium-copper strip. A supply of surplus boom material was obtained which was made by Fairchild and flown on the RCA SOOS program as gravity-gradient booms. The design of the tubular boom antenna dates back to the 1960s and was the subject of various papers presented in the 2nd, 3rd, and 4th Mechanisms Symposia.

The tubular boom was stowed by being manually flattened and rolled up onto a small, lightweight spool. Once in space, the spool unwound so that the boom formed into a 20-meter-long tube. A high degree of confidence was achieved by using this existing boom stock which had been used successfully in previous flight programs.

The first half of the antenna (closest to the spacecraft) was required to be covered with an insulating Kapton film. This was easily achieved by the application of standard adhesive-backed Kapton tape to the boom. Other modifications to the existing booms were that they were trimmed to length and holes were made at the base for attachment.

The Spool

The boom was rolled up on a spool in a way which provided very good packaging and support during launch. The inner part or the flanged sides of the spool were based on existing designs which have a slight taper toward the middle which forces the boom to peel off the spool in a controlled manner. Critical wear surfaces of the aluminum flanges were hard anodized which was essential to the smooth deployment of the boom.

A spur gear was added to each end of the spool as part of the geared kick-off feature. The pitch diameter of the gear was designed to be the same as the outer diameter of the stowed boom. A Delrin knob was also added to each end of the spool to register it in the guide slot in the base.

Testing

Development and testing of the design was limited to verifying the deployment mechanism since the tubular antenna and spool design had already been proven by flight experience. Short sections of boom material approximately 3 meters long were used to test the mechanism. A spacer was added to the spool to represent the missing 17 meters. The unit was then deployed many times in various conditions including vertically upwards, vertically downwards, horizontal, with and without Kapton tape applied. Most of the deployment kinematics were developed with these tests.

Two flight units were then loaded with short booms which were sent to Cornell for vibration testing. Each unit had a 3-meter boom loaded onto the spool and a non-flight pyrotechnic pin-puller integrated into the launch restraint. One of the booms was covered with Kapton tape and the other was left bare. After the test, the units were returned to ABLE where they were mounted upside down and deployed by actuating the pin-puller.

The final flight assembly was then made with the full-length flight booms loaded onto the spools and the flight pin-pullers integrated into the launch restraints. The units were then shipped to Cornell and integrated into the spacecraft. The deployable booms and mechanisms were then visually inspected for any abnormality. This visual check out was the final verification of the units.

Problem Areas

Three problems were encountered in the development of the new deployer design:

1. The root strength of the boom was found to be inadequate for the spin-up phase of the mission. The attachment of the inboard end of the boom was critical to its overall strength. The first design allowed the root to twist which reduced the bending strength of the boom. A translating collar was added which moved into position as the boom deployed to lock the root in place. This greatly improved the root attachment of the boom which was then able to meet the bending strength requirements.

2. The use of Kapton tape was a simple and effective method for insulating the boom, however it did have an adverse affect on the boom deployment. The tape was applied when the boom was in a flat condition and this prevented the boom from achieving its deployed tubular shape. A tool was made to add small longitudinal slits to the film which then allowed the boom to deploy normally.

3. The pyrotechnic pin-puller was held in place by a small Delrin clamp. After the firing of the test units, a small crack was observed in the side of one of the clamps. An examination of the problem showed that when the pin-puller was actuated, it expanded in the area of the clamp which caused the crack. No adverse effects were found due to the crack but new clamps were installed for the flight units and no further action was taken.

Conclusion

The tubular boom deployment mechanism has been shown to be a reliable and inexpensive alternative to older systems. Throughout ground testing and the flight mission the mechanism proved to be quite dependable. The success of the boom deployment mechanism was largely due to keeping the design simple and by using standard materials and fasteners whenever possible.